

# Top quark as a window to new physics

Michihisa Takeuchi

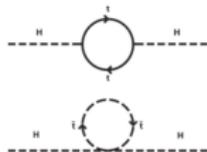
Universität Heidelberg

Copenhagen, 11th April 2012

# Top at the LHC

## closest to new physics $\rightarrow$ probe for new physics

- fine tuning problem: cancellation via top partner
- Tevatron anomalies ( $A_{FB}^t$ , single top etc. )
- copiously produced via strong interaction at LHC  $\rightarrow$  precision physics
  - $7\text{TeV LHC} \sim 800,000 \bar{t}t$
  - Tevatron  $\sim 40,000 \bar{t}t$
- Today's talk: stop search,  $A_{FB}^t$



## hadronic top $t \rightarrow 3j$

- full momentum reconstruction possible in principle  $\rightarrow$  important beyond discovery
- top against  $10^3$  larger QCD, how to identify?
  - $\sigma_{tt}^{14\text{TeV}} = 918 \text{ pb} \leftrightarrow \sigma_{3j}^{14\text{TeV}} \sim 2 \cdot 10^6 \text{ pb}$
- 3 jets with simple  $m_t, m_W$  condition  $\rightarrow$  large QCD combinatorial BG kill us

# Boosted Tops at the LHC

Boosted Top

HEPTopTagger

Applications

Summary

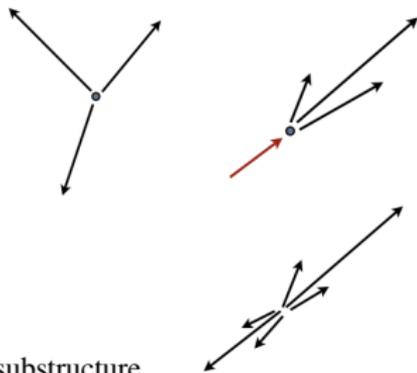
## massive jet

- top at rest  $\rightarrow$  separate 3 jets
- boosted top  $\rightarrow$  massive jet  
 $R \sim 2m/p_T$

- take massive jet & look into jet substructure

QCD combinatorics significantly reduced

QCD massive jet: soft-collinear nature in its substructure



# Boosted Tops at the LHC

## Boosted Top

### HEPTopTagger

### Applications

### Summary

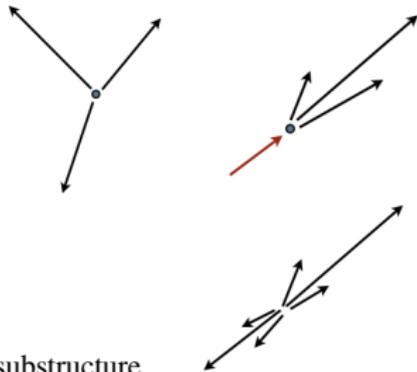
## massive jet

- top at rest  $\rightarrow$  separate 3 jets
- boosted top  $\rightarrow$  massive jet  
 $R \sim 2m/p_T$

- take massive jet & look into jet substructure

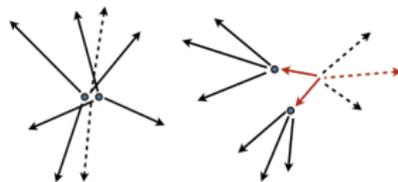
QCD combinatorics significantly reduced

QCD massive jet: soft-collinear nature in its substructure



## top as a probe

- new physics search with  $\cancel{E}_T$   $\rightarrow$  need recoil
  - top at rest: not useful
  - boosted tops: carry information on dark matter  
better  $S/B$  (cf.  $M_{T2}$  end point.)



# Boosted Tops at the LHC

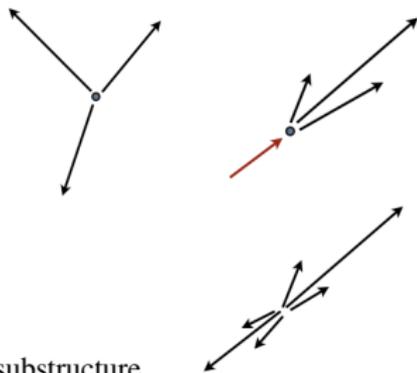
## massive jet

- top at rest  $\rightarrow$  separate 3 jets
- boosted top  $\rightarrow$  massive jet  
 $R \sim 2m/p_T$

- take massive jet & look into jet substructure

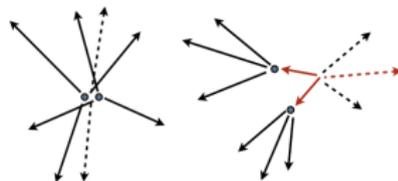
QCD combinatorics significantly reduced

QCD massive jet: soft-collinear nature in its substructure



## top as a probe

- new physics search with  $\cancel{E}_T \rightarrow$  need recoil
  - top at rest: not useful
  - boosted tops: carry information on dark matter  
better  $S/B$  (cf.  $M_{T2}$  end point.)



## top taggers

several top taggers available: focus on  $p_T > 500$  GeV.

[Kaplan, Rehermann, Schwartz, Tweedie] [Thaler, Wang] [Almeida, Lee, Perez, Stermann, Sung]

# Moderately Boosted Tops at the LHC

Boosted Top

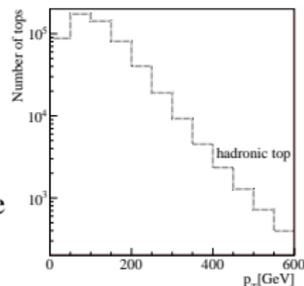
HEPTopTagger

Applications

Summary

## top $p_T$ distribution

- not expected many in SM for  $p_T > 500$  GeV
  - $\sigma(p_T > 200 \text{ GeV}) \sim 50\sigma(p_T > 500 \text{ GeV})$
- need top tagger valid down to low  $p_T$  range  $\rightarrow$  testable



## Moderately Boosted Tops at the LHC

Boosted Top

HEPTopTagger

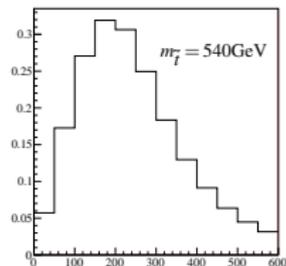
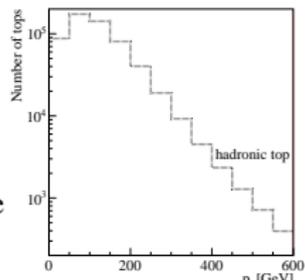
Applications

Summary

top  $p_T$  distribution

- not expected many in SM for  $p_T > 500$  GeV
  - $\sigma(p_T > 200 \text{ GeV}) \sim 50\sigma(p_T > 500 \text{ GeV})$
- need top tagger valid down to low  $p_T$  range  $\rightarrow$  testable
  
- light top partner also provide tops in the same range

we focus on  $p_T > 200 \text{ GeV}$

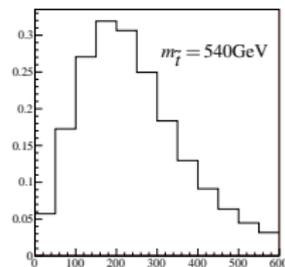
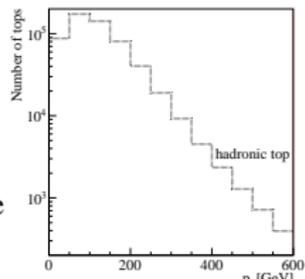


## Moderately Boosted Tops at the LHC

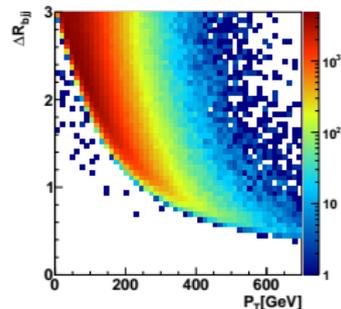
top  $p_T$  distribution

- not expected many in SM for  $p_T > 500$  GeV
  - $\sigma(p_T > 200 \text{ GeV}) \sim 50\sigma(p_T > 500 \text{ GeV})$
- need top tagger valid down to low  $p_T$  range  $\rightarrow$  testable
- light top partner also provide tops in the same range

we focus on  $p_T > 200$  GeV

fat jet – C/A with  $R = 1.5$ 

- top  $p_T$  vs.  $R_{jjj}$  distribution
- to catch  $t \rightarrow jjj$  with  $p_T \sim 200$  GeV
  - $\rightarrow$  need  $R = 1.5$

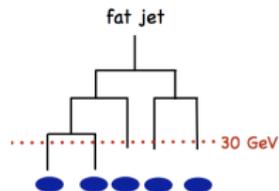
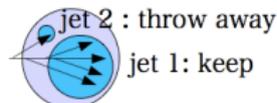
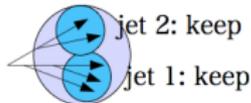


# 1. fat jets – C/A with $R = 1.5$ , $p_T^{\text{fatjet}} > 200 \text{ GeV}$

1. **fat jets** – C/A with  $R=1.5$ ,  $p_T^{\text{fatjet}} > 200$  GeV

2. **find subjects by mass drop criterion**

– keep  $j_1$  and  $j_2$  for  $m_{j_1} < 0.8m_j$  until  $m_j < 30$  GeV



$$j = j_1 + j_2$$

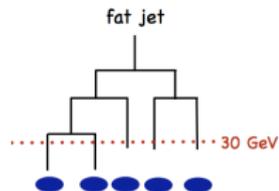
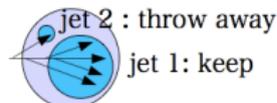
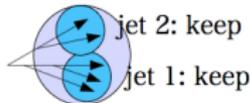
$$m_j \gg m_{j_1}, m_{j_2} \text{ (decay)}$$

$$\leftrightarrow m_j \sim m_{j_1} \gg m_{j_2} \text{ (QCD)}$$

1. **fat jets** – C/A with  $R=1.5$ ,  $p_T^{\text{fatjet}} > 200$  GeV

2. **find subjects by mass drop criterion**

– keep  $j_1$  and  $j_2$  for  $m_{j_1} < 0.8m_j$  until  $m_j < 30$  GeV



$$j = j_1 + j_2$$

$$m_j \gg m_{j_1}, m_{j_2} \text{ (decay)}$$

$$\leftrightarrow m_j \sim m_{j_1} \gg m_{j_2} \text{ (QCD)}$$

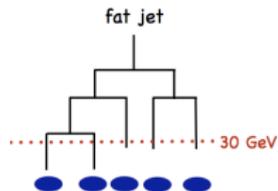
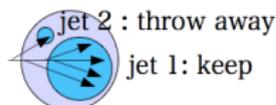
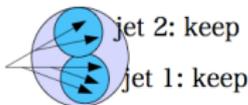
3. **take 3 subjects with best filtered mass**

–  $|m_{ij}^{\text{filt}} - m_t| < 25$  GeV  $\rightarrow$  **top candidate**

1. **fat jets** – C/A with  $R=1.5$ ,  $p_T^{\text{fatjet}} > 200$  GeV

2. **find subjects by mass drop criterion**

– keep  $j_1$  and  $j_2$  for  $m_{j_1} < 0.8m_j$  until  $m_j < 30$  GeV



$$j = j_1 + j_2$$

$$m_j \gg m_{j_1}, m_{j_2} \text{ (decay)}$$

$$\leftrightarrow m_j \sim m_{j_1} \gg m_{j_2} \text{ (QCD)}$$

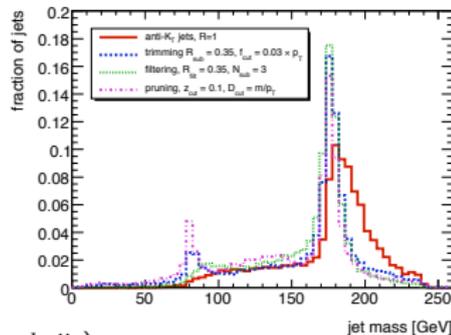
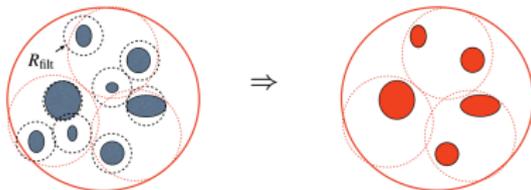
3. **take 3 subjects with best filtered mass**

–  $|m_{ijj}^{\text{filt}} - m_t| < 25$  GeV  $\rightarrow$  **top candidate**

## filtering

[Butterworth et al.]

- effect of pile-up, underlying events  $\sim R^2$
- reduce effective area with smaller  $R_{\text{filt}}$  and  $n_{\text{filt}}$

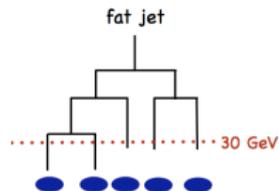
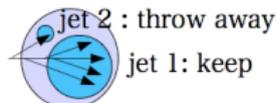
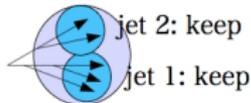


–  $R_{\text{filt}} = \min\{0.3, R_{ij}/2\}$  and  $n_{\text{filt}} = 5$  ( $t \rightarrow bWg \rightarrow bgjjg$ )

1. **fat jets** – C/A with  $R=1.5$ ,  $p_T^{\text{fatjet}} > 200$  GeV

2. **find subjects by mass drop criterion**

– keep  $j_1$  and  $j_2$  for  $m_{j_1} < 0.8m_j$  until  $m_j < 30$  GeV



$$j = j_1 + j_2$$

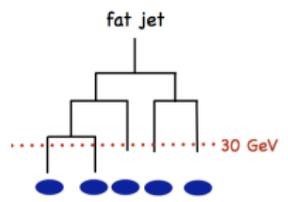
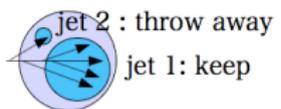
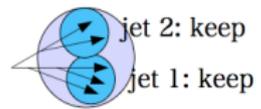
$$m_j \gg m_{j_1}, m_{j_2} \text{ (decay)}$$

$$\leftrightarrow m_j \sim m_{j_1} \gg m_{j_2} \text{ (QCD)}$$

3. **take 3 subjects with best filtered mass**

–  $|m_{ij}^{\text{filt}} - m_t| < 25$  GeV  $\rightarrow$  **top candidate**

- fat jets** – C/A with  $R=1.5$ ,  $p_T^{\text{fatjet}} > 200$  GeV
- find subjects by mass drop criterion**
  - keep  $j_1$  and  $j_2$  for  $m_{j_1} < 0.8m_j$  until  $m_j < 30$  GeV



$$j = j_1 + j_2 \quad \left[ m_j \gg m_{j_1}, m_{j_2} \text{ (decay)} \right] \leftrightarrow \left[ m_j \sim m_{j_1} \gg m_{j_2} \text{ (QCD)} \right]$$

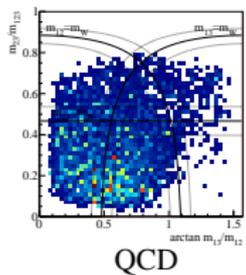
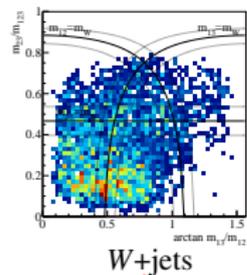
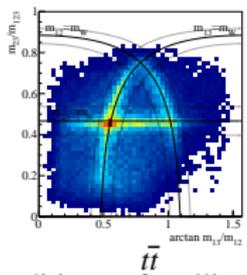
**3. take 3 subjects with best filtered mass**

- $|m_{jjj}^{\text{filt}} - m_t| < 25$  GeV  $\rightarrow$  **top candidate**

**4. check mass ratios**

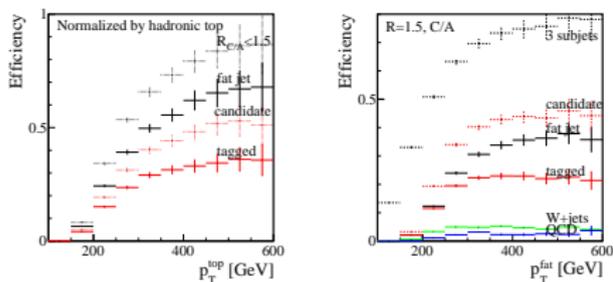
- 3 subjects:  $p_1, p_2, p_3 \rightarrow m_{12}, m_{13}, m_{23}$
- $m_t$  condition:  $m_t^2 = m_{123}^2 = m_{12}^2 + m_{13}^2 + m_{23}^2 \rightarrow$  spherical surface: 2D mass ratios

$$\begin{aligned} m_{23} &\downarrow 0 \\ 0 &\leftarrow m_{13} \\ m_{12} &\rightarrow 0 \end{aligned}$$



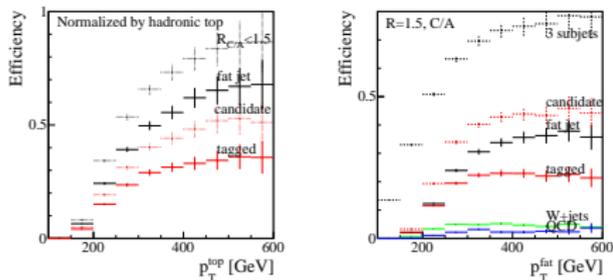
- $W$  mass condition, soft-collinear cut  $\rightarrow$  **tagged top**

## efficiency



- efficiency  $\sim 30\%$  for hadronic tops,  $2 \sim 4\%$  mis-tag rate
- validation with ATLAS experimentalists in Heidelberg [G. Kasieczka, S. Schätzel, A. Schöning]

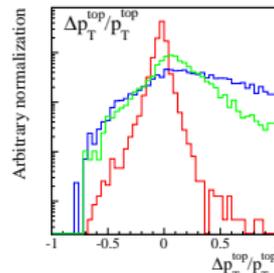
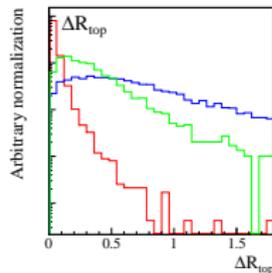
## efficiency



- efficiency  $\sim 30\%$  for hadronic tops,  $2 \sim 4\%$  mis-tag rate
- validation with ATLAS experimentalists in Heidelberg [G. Kasieczka, S. Schätzel, A. Schöning]

## momentum reconstruction

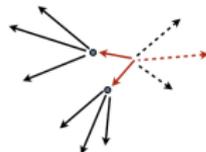
- well reconstructed
- better for larger  $p_T$



# Scalar Top Pairs at 14 TeV

## hadronic mode [T. Plehn, M. Spannowsky, MT, D. Zerwas]

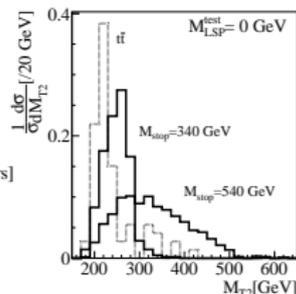
- $\tilde{t}_1 \tilde{t}_1^* \rightarrow (t\tilde{\chi}_1^0)(\bar{t}\tilde{\chi}_1^0)$
- main BG:  $t\bar{t}$ +jets,  $W$ +jets and QCD



events in $1 \text{ fb}^{-1}$	$\tilde{t}_1 \tilde{t}_1^*$	$t\bar{t}$	QCD	W+jets	Z+jets	$S/B$	$S/\sqrt{B}$
$m_T$ [GeV]	340 390 440 490 540 640					340	$10 \text{ fb}^{-1}$
$p_{T,j} > 200 \text{ GeV}, \ell \text{ veto}$	728 447 292 187 124 46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$3.0 \cdot 10^{-5}$	
$\cancel{E}_T > 150 \text{ GeV}$	283 234 184 133 93 35	2245	$2.4 \cdot 10^5$	1710	2240	$1.2 \cdot 10^{-3}$	
first top tag	100 91 75 57 42 15	743	7590	90	114	$1.2 \cdot 10^{-2}$	
second top tag	15 12.4 11 8.4 6.3 2.3	32	129	5.7	1.4	$8.3 \cdot 10^{-2}$	
$b$ -tag for 1 <sup>st</sup> top tag	8.7 7.4 6.3 5.0 3.8 1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.40	5.9
$m_{T2} > 250 \text{ GeV}$	4.3 5.0 4.9 4.2 3.2 1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	0.88	6.1

$$S/B \sim 1, S/\sqrt{B} > 5 \text{ at } 14 \text{ TeV with } 10 \text{ fb}^{-1}$$

- stop mass from  $m_{T2}(m_{\tilde{\chi}_1^0})$  endpoint [C. G. Lester, D. J. Summers]
- like sleptons or sbottoms



## semi-leptonic mode [JHEP 1105 (2011) 135 [arXiv:1102.0557 [hep-ph]], T. Plehn, M. Spannowsky, MT]

- boosted leptonic top

$$S/B \sim 2, S/\sqrt{B} > 5 \text{ at } 14 \text{ TeV with } 10 \text{ fb}^{-1}$$

# Scalar Top Pairs at 8TeV

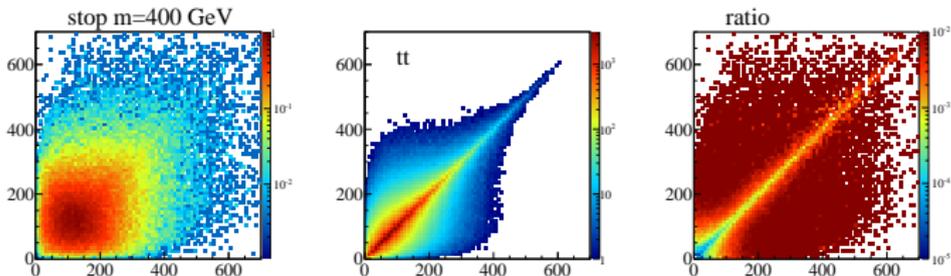
[T. Plehn, M. Spannowsky, MT]

- $\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}}$ : both for  $t\bar{t}$  and  $\tilde{t}_1\tilde{t}_1^*$
- low statistics with 2 boosted tops:  $S/B \sim 1, S/\sqrt{B} \sim 2$  for  $10 \text{ fb}^{-1}$

# Scalar Top Pairs at 8TeV

[T. Plehn, M. Spannowsky, MT]

- $\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}}$ : both for  $t\bar{t}$  and  $\tilde{t}_1\tilde{t}_1^*$
- low statistics with 2 boosted tops:  $S/B \sim 1, S/\sqrt{B} \sim 2$  for  $10 \text{ fb}^{-1}$

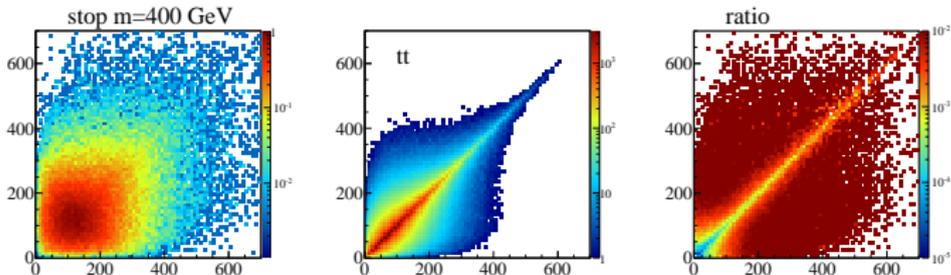


- 1 boosted top and 1 non-boosted top

# Scalar Top Pairs at 8TeV

[T. Plehn, M. Spannowsky, MT]

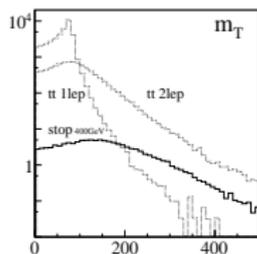
- $\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}}$ : both for  $t\bar{t}$  and  $\tilde{t}_1\tilde{t}_1^*$
- low statistics with 2 boosted tops:  $S/B \sim 1, S/\sqrt{B} \sim 2$  for  $10 \text{ fb}^{-1}$



- 1 boosted top and 1 non-boosted top
- semi-leptonic mode: 1 hadronic top-tag +  $\ell, \cancel{E}_T$

# Scalar Top Pairs at 8TeV [T. Plehn, M. Spannowsky, MT]

- $\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}}$ : both for  $t\bar{t}$  and  $\tilde{t}_1\tilde{t}_1^*$
- low statistics with 2 boosted tops:  $S/B \sim 1, S/\sqrt{B} \sim 2$  for  $10 \text{ fb}^{-1}$

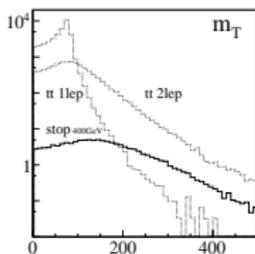


- 1 boosted top and 1 non-boosted top
- semi-leptonic mode: 1 hadronic top-tag +  $\ell, \cancel{E}_T$   
 BG:  $t\bar{t} \rightarrow t_h + b\ell\nu$ : negligible with  $m_T(\ell, \cancel{E}_T) > 150 \text{ GeV}$   
 $t\bar{t} \rightarrow b\bar{b} + \tau_h\ell + 2\nu$ : fake hadronic top tag with ISR or  $\tau_h$   
 $\rightarrow$  subjet id:  $b$ -tag,  $\tau_h$  rejection possible?

# Scalar Top Pairs at 8TeV

[T. Plehn, M. Spannowsky, MT]

- $\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}}$ : both for  $t\bar{t}$  and  $\tilde{t}_1\tilde{t}_1^*$
- low statistics with 2 boosted tops:  $S/B \sim 1, S/\sqrt{B} \sim 2$  for  $10 \text{ fb}^{-1}$

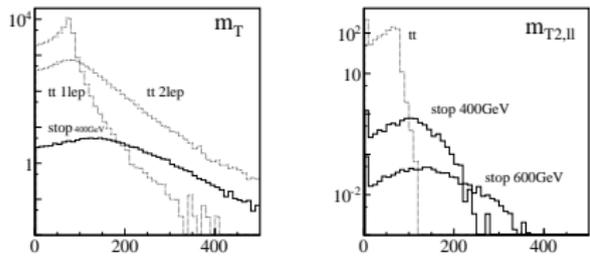


- 1 boosted top and 1 non-boosted top
  - semi-leptonic mode: 1 hadronic top-tag +  $\ell, \cancel{E}_T$
- BG:  $t\bar{t} \rightarrow t_h + b\ell\nu$ : negligible with  $m_T(\ell, \cancel{E}_T) > 150 \text{ GeV}$   
 $t\bar{t} \rightarrow b\bar{b} + \tau_h\ell + 2\nu$ : fake hadronic top tag with ISR or  $\tau_h$   
 $\rightarrow$  subset id:  $b$ -tag,  $\tau_h$  rejection possible?

$\sqrt{s} = 8 \text{ TeV}, R = 1.5$	$\tilde{t}_1\tilde{t}_1^*$							$t\bar{t}$	$S/B S/\sqrt{B}_{10\text{fb}^{-1}}$	
$m_T$ [GeV]	350	400	450	500	600	700			400	
cross section [fb]	760	337	160	80.5	23.0	7.19	$1.63 \cdot 10^5$			
$n_\ell = 1, \cancel{E}_T > 100 \text{ GeV}, n_{\text{fat}} \geq 1$	104.37	61.49	34.81	19.54	6.28	2.11	3901.06			
$n_{\text{tag}} = 1$	13.09	9.02	5.80	3.60	1.33	0.50	546.89			
$m_T > 150 \text{ GeV}$	4.63	4.27	3.25	2.19	0.94	0.38	2.17	2.0	9.2	
$j_b = b$	1.47	1.38	1.06	0.70	0.31	0.13	0.40	3.5	6.9	
$j_b = b \& j_{W1} \neq b \& j_{W2} \neq b$	1.33	1.27	0.97	0.65	0.29	0.12	0.31	4.1	7.3	
reject $\tau_h$	4.45	4.13	3.15	2.11	0.91	0.36	1.52	2.7	10.6	
$j_b = b \& j_{W1} \neq b$ with reject $\tau_h$	1.33	1.27	0.97	0.65	0.29	0.12	0.13	9.8	11.1	

# Scalar Top Pairs at 8TeV [T. Plehn, M. Spannowsky, MT]

- $\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}}$ : both for  $t\bar{t}$  and  $\tilde{t}_1\tilde{t}_1^*$
- low statistics with 2 boosted tops:  $S/B \sim 1, S/\sqrt{B} \sim 2$  for  $10 \text{ fb}^{-1}$



$$m_{T2} = \min_{\cancel{E}_T \text{ split}} \left[ \max \{ m_T^{\ell_1}, m_T^{\ell_2} \} \right]$$

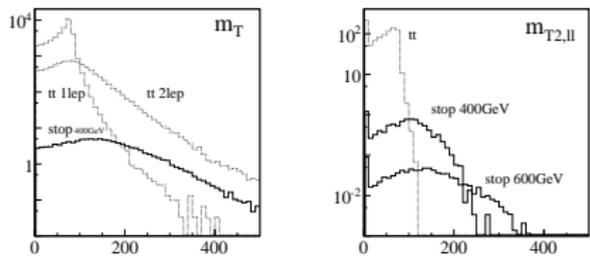
- 1 boosted top and 1 non-boosted top
- semi-leptonic mode: 1 hadronic top-tag +  $\ell, \cancel{E}_T$   
 BG:  $t\bar{t} \rightarrow t_h + b\ell\nu$ : negligible with  $m_T(\ell, \cancel{E}_T) > 150 \text{ GeV}$   
 $t\bar{t} \rightarrow b\bar{b} + \tau_h\ell + 2\nu$ : fake hadronic top tag with ISR or  $\tau_h$   
 → subset id:  $b$ -tag,  $\tau_h$  rejection possible?

$\sqrt{s} = 8 \text{ TeV}, R = 1.5$	$\tilde{t}_1\tilde{t}_1^*$						$t\bar{t}$	$S/B$	$S/\sqrt{B}_{10\text{fb}^{-1}}$
$m_T$ [GeV]	350	400	450	500	600	700		400	
$n_\ell = 1, \cancel{E}_T > 100 \text{ GeV}, n_{\text{fat}} \geq 1$	104.37	61.49	34.81	19.54	6.28	2.11	3901.06		
$m_T > 150 \text{ GeV}, n_{\text{tag}} = 1$	4.63	4.27	3.25	2.19	0.94	0.38	2.17	2.0	9.2
$(j_b, j_{W1}, j_{W2}) = (b, q, q)$	1.33	1.27	0.97	0.65	0.29	0.12	0.31	4.1	7.3

- di-lepton mode:  
 BG:  $t\bar{t} \rightarrow b\bar{b} + \ell\ell + 2\nu$ : negligible with  $m_{T2,\ell\ell} > 100 \text{ GeV}$

# Scalar Top Pairs at 8TeV [T. Plehn, M. Spannowsky, MT]

- $\sigma^{8\text{TeV}} \sim \frac{1}{10} \sigma^{14\text{TeV}}$ : both for  $t\bar{t}$  and  $\tilde{t}_1\tilde{t}_1^*$
- low statistics with 2 boosted tops:  $S/B \sim 1, S/\sqrt{B} \sim 2$  for  $10 \text{ fb}^{-1}$



$$m_{T2} = \min_{\cancel{E}_T \text{ split}} \left[ \max\{m_T^{\ell_1}, m_T^{\ell_2}\} \right]$$

- 1 boosted top and 1 non-boosted top
- semi-leptonic mode: 1 hadronic top-tag +  $\ell, \cancel{E}_T$   
 BG:  $t\bar{t} \rightarrow t_h + b\ell\nu$ : negligible with  $m_T(\ell, \cancel{E}_T) > 150 \text{ GeV}$   
 $t\bar{t} \rightarrow b\bar{b} + \tau_h\ell + 2\nu$ : fake hadronic top tag with ISR or  $\tau_h$   
 → subject id:  $b$ -tag,  $\tau_h$  rejection possible?

$\sqrt{s} = 8 \text{ TeV}, R = 1.5$	$\tilde{t}_1\tilde{t}_1^*$						$t\bar{t}$	$S/B \text{ } S/\sqrt{B}$
	350	400	450	500	600	700		$10\text{fb}^{-1}$
$m_T$ [ GeV ]								400
$n_\ell = 1, \cancel{E}_T > 100 \text{ GeV}, n_{\text{fat}} \geq 1$	104.37	61.49	34.81	19.54	6.28	2.11	3901.06	
$m_T > 150 \text{ GeV}, n_{\text{tag}} = 1$	4.63	4.27	3.25	2.19	0.94	0.38	2.17	2.0 9.2
$(j_b, j_{W1}, j_{W2}) = (b, q, q)$	1.33	1.27	0.97	0.65	0.29	0.12	0.31	4.1 7.3

- di-lepton mode:  
 BG:  $t\bar{t} \rightarrow b\bar{b} + \ell\ell + 2\nu$ : negligible with  $m_{T2,\ell\ell} > 100 \text{ GeV}$

$m_T$ [ GeV ]	350	400	450	500	600	700	$t\bar{t}$	$S/B \text{ } S/\sqrt{B}$
								$10\text{fb}^{-1}$
$n_\ell = 2, \cancel{E}_T > 100\text{GeV}$	19.04	9.99	5.40	2.94	0.91	0.30	911.25	
$m_{T2,\ell\ell} > 100\text{GeV}$	6.05	4.30	2.70	1.65	0.56	0.20	0.46	9.3 20
$m_{T2,\ell\ell} > 150\text{GeV}$	0.81	1.21	1.06	0.81	0.34	0.14	0.00	- -

# Top forward backward asymmetry $A_{FB}^t$

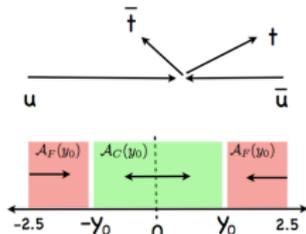
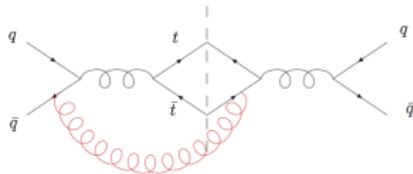
[Phys.Rev. D84 (2011) 054005 [arXiv:1103.4618 [hep-ph]], J. L. Hewett, J. Shelton, M. Spannowsky, T.M.P. Tait, MT]

- QCD  $A_{FB}^t$ : small NLO effect ( $\sim 6\%$ )
- D0 and CDF observed anomalously large  $A_{FB}^t$

$$\text{D0: } A_{FB}^t = 8 \pm 4 \pm 1\%$$

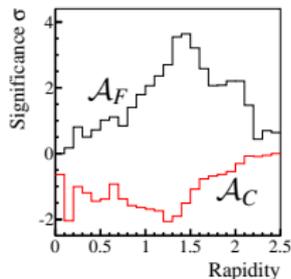
$$\text{CDF: } A_{FB}^t = 15 \pm 5 \pm 2.4\%$$

- LHC (pp collider): charge asymmetry in forward-central region



anti-tops are more central

- semi-leptonic mode:  $t\bar{t} \rightarrow (bjj)(bl\nu)$ 
  - one isolated lepton
  - one hadronic top tagged with HEPTopTagger
  - $b$ -tag in tagged top  $\rightarrow W$ +jets negligible
  - top charge determined by lepton
- SM:  $5\sigma$  after  $60\text{fb}^{-1}$  (14TeV)
- BSM:  $5\sigma$  after  $2\text{fb}^{-1}$  (14TeV)  
 $2.8\sigma$  after  $10\text{fb}^{-1}$  (7TeV)



# Summary

**HEPTopTagger** available on <http://www.thphys.uni-heidelberg.de/~plehn/>

- focus on moderate  $p_T$  tops ( $p_T > 200\text{GeV}$ )  $\rightarrow$  testable in SM
- fat jets kill combinatorics
- jet substructure: thrown information, use all available information
- momentum well reconstructed

general idea: tops at LHC identified just like bottoms

## Applications

- stop pairs
  - at 14 TeV with  $10\text{fb}^{-1}$  (2 boosted top analysis)
  - hadronic channel:  $S/B \sim 1, S/\sqrt{B} > 5$
  - semi-leptonic channel:  $S/B \sim 2, S/\sqrt{B} > 5$

at 8 TeV with  $10\text{fb}^{-1}$

- hadronic:  $S/B \sim 1, S/\sqrt{B} \sim 2$
- semi-leptonic:  $S/B \sim 4, S/\sqrt{B} \sim 7$
- di-leptonic:  $S/B \sim 9, S/\sqrt{B} \sim 20$

- $A_{FB}^t$  at 14 TeV
  - SM:  $5\sigma$  with  $60\text{fb}^{-1}$
  - BSM:  $5\sigma$  with  $2\text{fb}^{-1}$  ( $2.8\sigma$  at 7TeV with  $10\text{fb}^{-1}$ )

## questions

- How much can we do subject id: b-tag, tau-tag?
- How difficult is subject calibration?